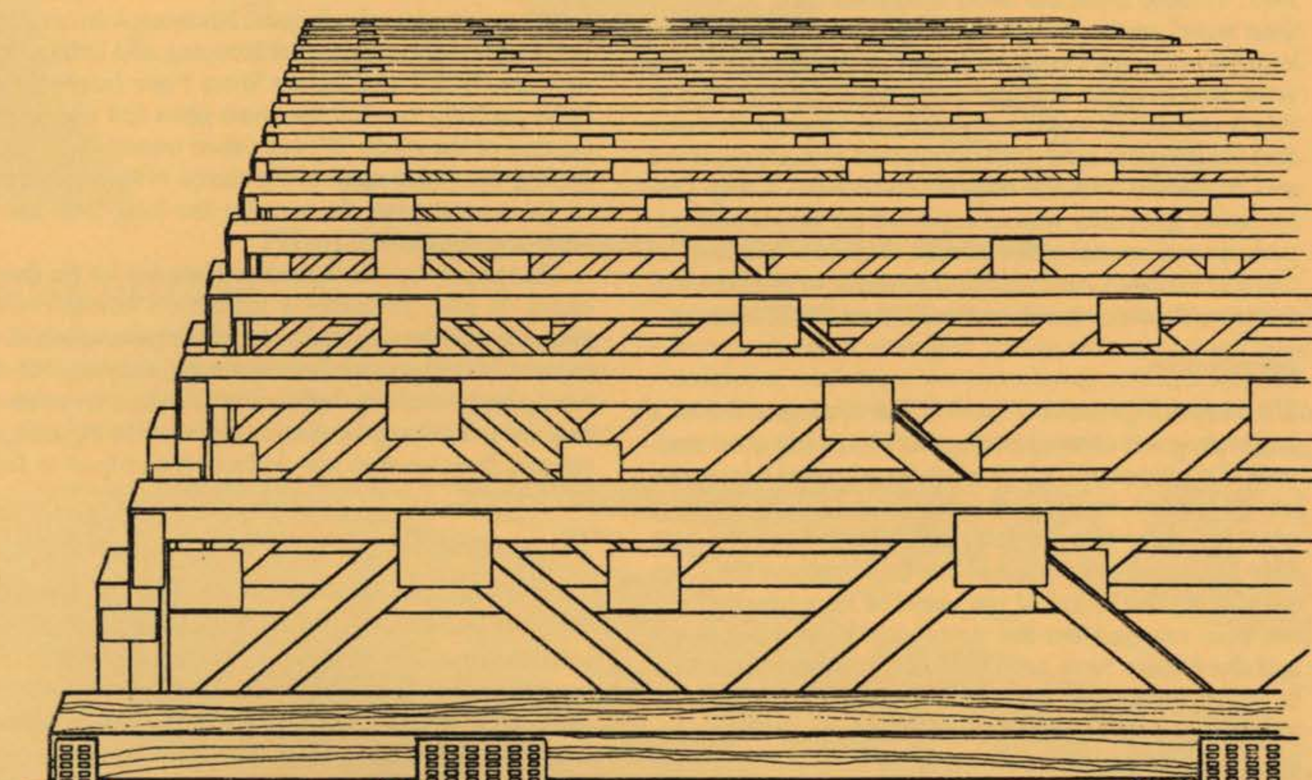
LONG-TERM TESTS OF 4X2 PARALLEL-CHORD METAL-PLATE-CONNECTED WOOD TRUSSES

ADDENDUM TO RESEARCH REPORT 81-1

Research Report 89-2



Small Homes Council-Building Research Council
University of Illinois at Urbana-Champaign

Long-Term Tests of 4 x 2 Parallel-Chord Metal-Plate-Connected Wood Trusses

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Abstract

Parallel-chord metal-plate-connected wood trusses of four different designs were load-tested to destruction in 1977. Trusses from the same manufacturing lots were then tested under design dead load plus one-half live load for ten years. Creep deflection performance records were kept over the ten-year period and are reported in this document. Strength tests of the trusses that had carried the ten-year load were conducted and are reported and compared with the original test results. Creep performance generally was as expected for wood with superimposed annual cyclic effects. With the exception of one set of trusses, no significant strength or stiffness losses were observed between the 1977 and 1987 tests.

Introduction

The research presented here is the final portion of a larger program encompassing short-term tests and analyses of six types of 4 x 2 parallel-chord metal-plate-connected trusses designed to carry floor loading. A prior report (2) describes the total program but reports data only from the first three and one-half years of the long-term tests. The target of ten years of long-term testing has been reached, the test units have been dismantled, and the trusses have been subjected to short-term tests to destruction. These short-term test results can be compared with earlier tests of trusses from the same manufacturing lots but not subjected to the long-term loading.

The long-term program included only four of the six original truss types since the samples of two types were not available at the time of long-term test initiation. A test unit of 2 x 10 floor joists was included in this program for comparison with truss performance. Loads were uniform at full dead load plus one-half the design live load. Such a total load is much higher than commonplace for residential floors and was judged to be more realistic for measuring performance than full design load.

In addition to being a cooperative effort between the University of Illinois and Purdue University, the study was supported by the Federal Housing Administration (FHA) of the Department of Housing and Urban Development (HUD) and by the Truss Plate Institute (TPI). FHA partially funded the short-term test and analysis portion of the study. TPI furnished materials and funds during the entire span of the study. With the exception of the second year, the rent for the long-term test site building was funded by TPI.

This paper reports deflection histories for the five test units. It also includes a tabulated comparison of strength of trusses tested shortly after manufacture and trusses from the same lots that were subjected to dead load plus half of the design live load for ten years. The trusses under long-term test are shown in Figure 1, and the test floor used to test deflection and load to failure in Figure 2.

Test Facilities

The long-term tests were set up in a 25 ft x 50 ft unheated concrete floored wood-frame building located in Brookston, Indiana, 12 miles north of Purdue University. Solid concrete blocks, bricks, and lead weights were used to provide uniform loads. Deflections were measured using a braided nylon line secured to the lower chord above one bearing and supported over a roller arrangement over the other bearing. A weight was attached at the roller end to maintain constant tension in the line. A millimeter scale with a mirror was fastened to the truss lower chord at the span center. This arrangement had been developed over a period of time and checked with dial gages. Reading accuracy within plus or minus one tenth millimeter over long time periods was demonstrated during the trials. Deflections measured in this manner are independent of movement in the supports.

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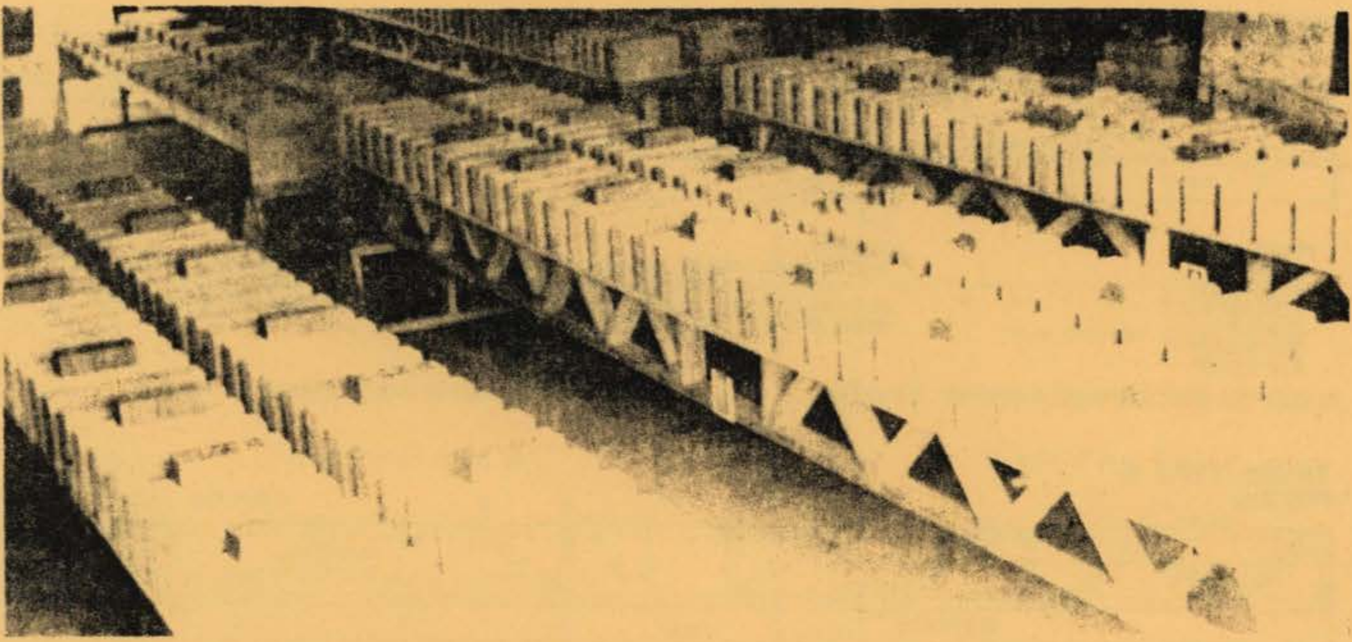

Figure 1. Trusses under long-term test at Dead Load plus 1/2 Live Load.

Test Units and Materials

At the beginning of this project, trusses were manufactured in groups of six within each type. Each truss type was assembled with different proprietary steel connector plates. Each truss type was designed by the truss plate manufacturer, Figure 3. Truss fabrication and delivery was also arranged by the manufacturer. Three trusses of each type were randomly selected and subjected to standard TPI short-term tests (3) in 1977. Two each of the remaining three trusses were randomly

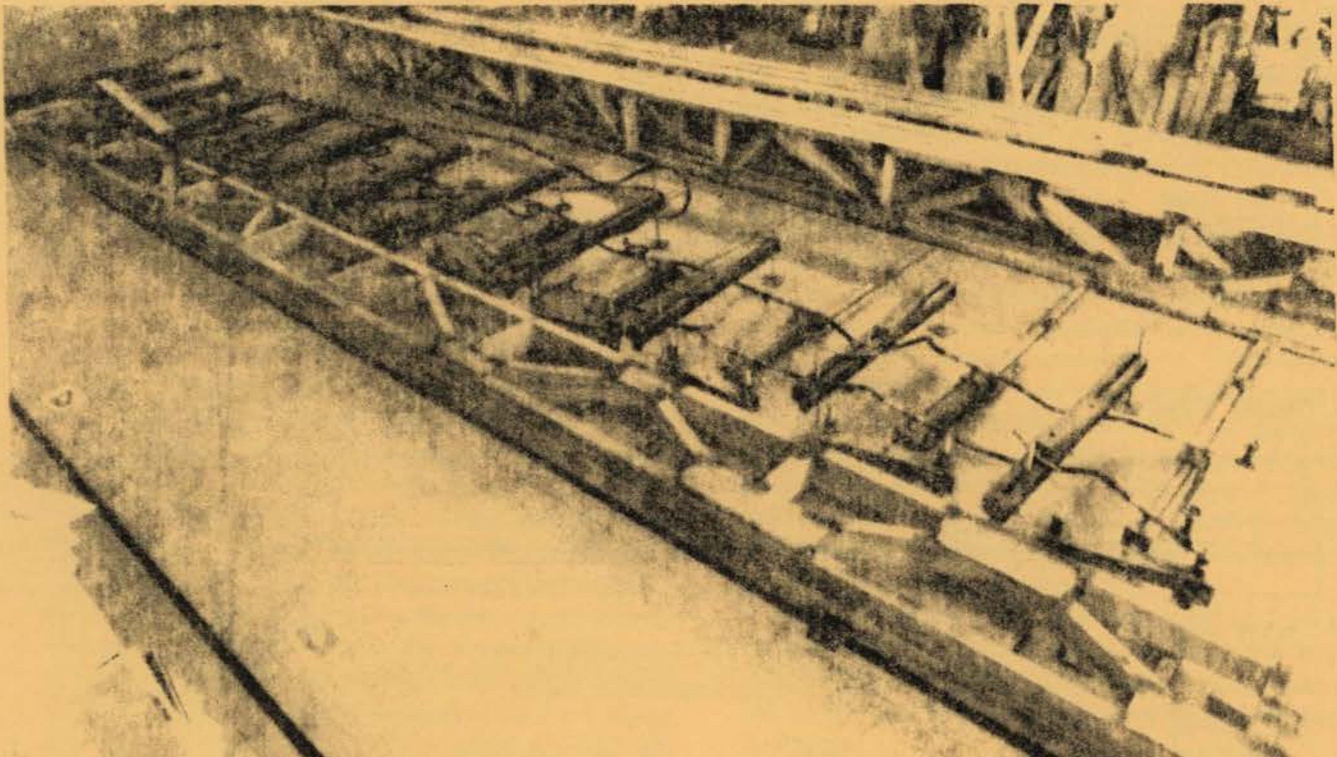

Figure 2. Truss being tested for deflection and load to failure.

TRUSS TYPE 1
FIGURE 1a

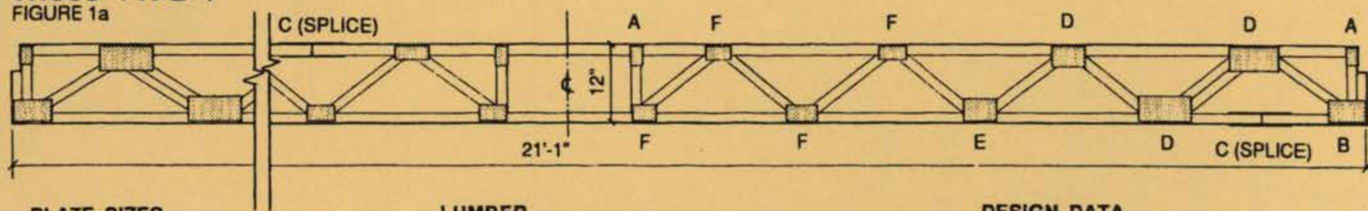

PLATE SIZES
A: 2" X 3"
B: 6" X 3-1/2"
C: 10-1/8" X 3"
D: 8" X 4"
E: 5" X 3-1/2"
F: 4" X 2-1/2"

LUMBER
TOP: SPIB NO. 1 DENSE, KD 2250F, (344), SYP;
SPIB NO. 1 DENSE, KD 2250F, (700), SYP,
BOTTOM: SPIB NO. 1 DENSE, KD 2250F, (720), SYP,
WEBS: SPIB NO. 1 DENSE, KD 2250F, (700), SYP

DESIGN DATA
TOP CHORD L.L.: 40 PSF
TOP CHORD D.L.: 10 PSF
BOTTOM CHORD D.L.: 5 PSF

TRUSS TYPE 2
FIGURE 1b

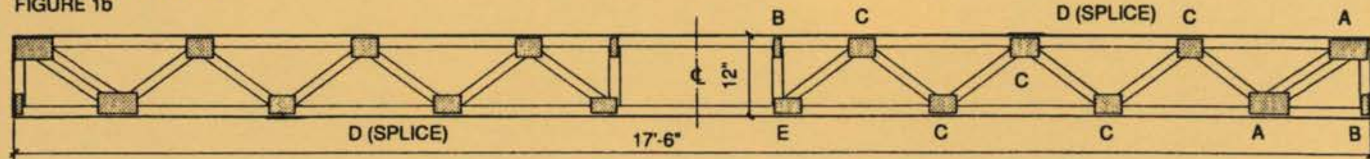

PLATE SIZES
A: 6" X 3-1/2"
B: 1" X 3"
C: 4" X 3"
D: 5" X 3"
E: 4" X 2-1/2"

LUMBER
TOP: SPIB NO. 2 DENSE, SYP,
BOTTOM: SPIB NO. 2 DENSE, KD 1850F, (403), SYP,
WEBS: SYP, NO VISIBLE GRADE MARKS

DESIGN DATA
TOP CHORD L.L.: 40 PSF
TOP CHORD D.L. : 10 PSF
BOTTOM CHORD D.L.: 10 PSF

TRUSS TYPE 3
FIGURE 1c

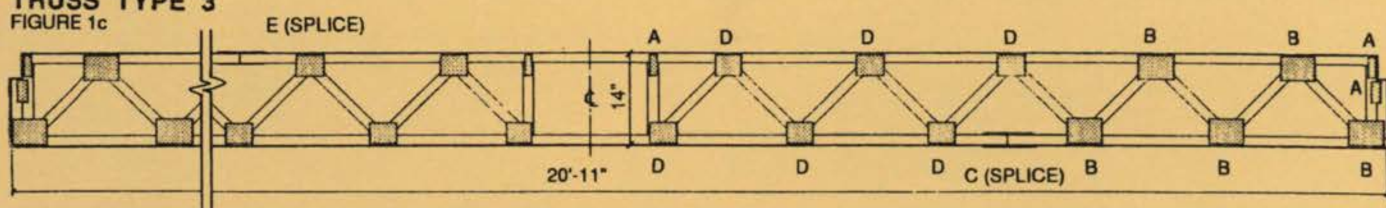

PLATE SIZES
A: 1-1/2" X 3-1/2"
B: 5-1/4" X 4"
C: 8" X 3"
D: 4" X 3-1/2"
E: 6-3/4" X 3"

LUMBER
TOP: SPIB NO. 2 DENSE, KD 1850F, (73), SYP,
BOTTOM: SPIB NO. 2 DENSE, KD 1850F, (73), SYP,
WEBS: SPIB NO. 2 DENSE, KD 1850F, (73), SYP

DESIGN DATA
TOP CHORD L.L.: 40 PSF
TOP CHORD D.L.: 10 PSF
BOTTOM CHORD D.L.: 5 PSF

TRUSS TYPE 4
FIGURE 1d

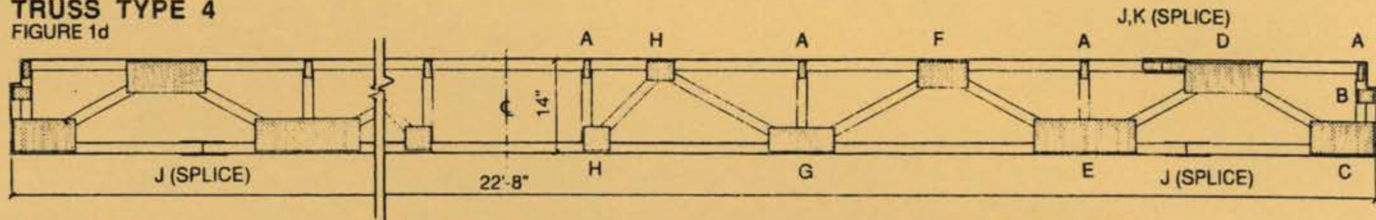

PLATE SIZES
A: 1" X 2-5/8"
B: 3" X 2"
C: 10-1/8" X 5"
D: 12-1/4" X 5"
E: 15-3/4" X 5"
F: 7-7/8" X 4"
G: 10-1/8" X 4"
H: 4" X 3"
J: 6-3/4" X 3"
K: 1" X 6-3/4"

LUMBER
TOP: SPIB NO. 1 DENSE, KD 2250F, SYP,
BOTTOM: SPIB NO. 1 DENSE, KD 2250F, (870), SYP,
WEBS: SYP, NO VISIBLE GRADE MARKS

DESIGN DATA
TOP CHORD L.L.: 40 PSF
TOP CHORD D.L.: 10 PSF
BOTOM CHORD D.L.: 5 PSF

Figure 3. Truss designs tested in the projects. Actual dimensions taken from the test units.

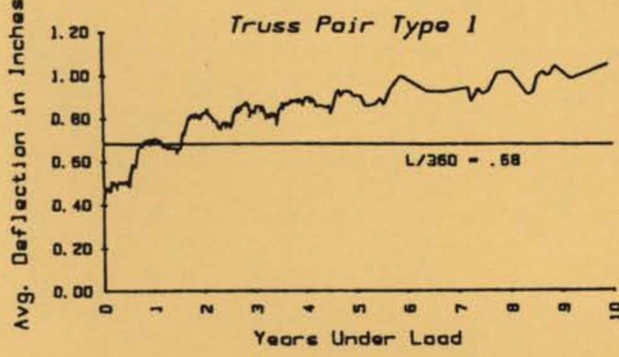

Figure 4. Deflection history of truss pair Type 1.

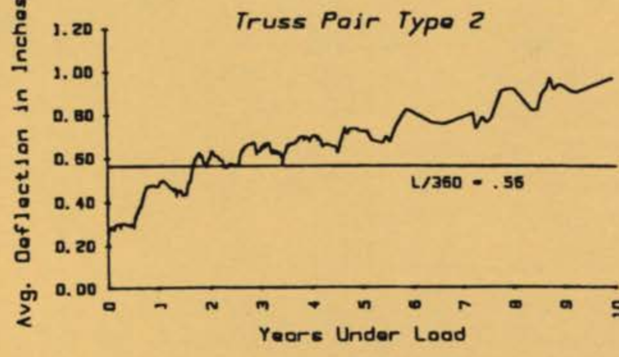

Figure 5. Deflection history of truss pair Type 2.

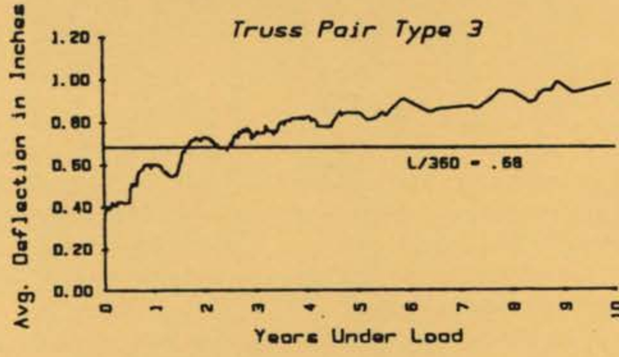

Figure 6. Deflection history of truss pair Type 3.

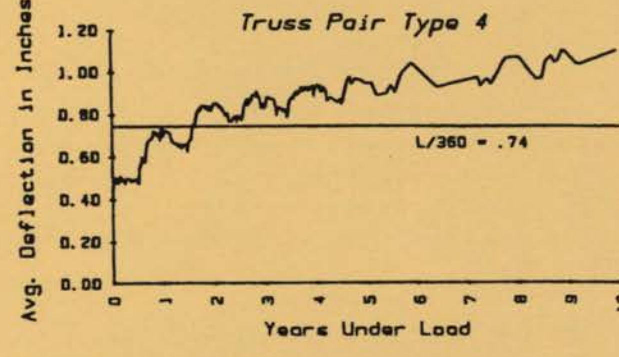

Figure 7. Deflection history of truss pair Type 4.

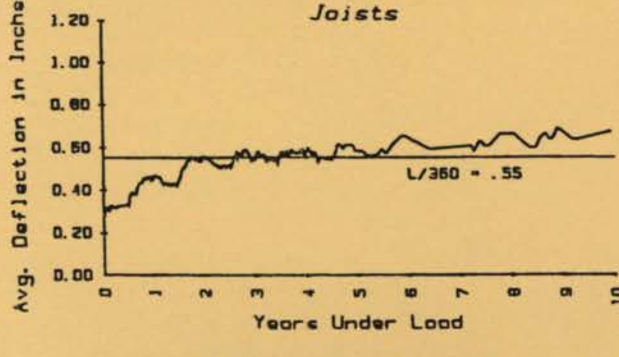

Figure 8. Deflection history of joists.

selected within each type for the long-term tests. Four truss types were available at that time.

The two 2 x 10 joists were chosen from a group of No. 2 KD Southern Pine 2 x 10's on the basis of their measured modulus of elasticity (MOE). The National Design Specification (NDS) tabular value of MOE for this grade and species is 1.6 million psi. Using an edgewise centerpoint load test on a 16-foot span, the two pieces selected were found to be very close to the tabular MOE. As required for the span and the design load, the joists were spaced 16 inches on center, supported on 2 x 4 plates, and sheathed with 5/8-inch tongue-and-grooved plywood. The design dead load was 10 psf, and the design live load 40 psf. The sheathing pieces were 4 feet wide and cut into 3-foot lengths with the face grain perpendicular to the axis of the joists. The sheathing was attached with 6d ring shank nails placed 8 inches on center. While the American Plywood Association (APA) "Plywood Residential Construction Guide" (1) specifies 8d deformed-shank nails for plywood subflooring, these nails could not be located among local building materials suppliers.

The APA Construction Guide specified 7/8-inch tongue-and-groove underlayment-grade plywood for 24-inch on center application, the normal spacing of floor trusses. After a concerted effort was made to locate the 7/8-inch tongue-and-groove underlayment plywood, it was found to be unavailable in the midwest area. Therefore, the decision was made to use 3/4-inch-thick tongue-and-groove underlayment on the four sets of floor trusses. The 3/4-inch underlayment plywood was cut into 3-foot by 4-foot pieces, placed in the same way as for the joist setup, and nailed 10 inches on center with 6d ring-shank nails.

The trusses and joists were supported on 2 x 4 reaction units simulating wall bearing on the bottom chords. Wood bridging (1x4) was used at the span center on the joist unit only. The floor truss units had no bridging.

The four pairs of trusses were actually assembled with a 20-inch on center spacing rather than the design

Table 1. Deflection at Two-Year Intervals

The 8-year and 10-year values were read in August. The others were read in September. The 2-year through 10-year readings and the residual deflection are reported as factors based upon initial deflection. The actual deflection can be obtained by multiplying the initial deflection by the factor. These factors provide a clearer indication of behavior within a type and allow a direct comparison of

Truss Pair Type	Initial Defl. Inches	2-year Defl. Factor	4-year Defl. Factor	6-year Defl. Factor	8-year Defl. Factor	10-year Defl. Factor	Residual Defl. Factor
1	0.341	2.41	2.59	2.93	2.98	3.10	1.45
2	0.175	3.38	3.90	4.70	5.21	5.54	3.50
3	0.287	2.54	2.85	3.17	3.27	3.41	1.68
4	0.337	2.52	2.72	3.10	3.18	3.28	1.61
Joists	0.234	2.37	2.44	2.80	2.82	2.88	1.28

24-inch on center spacing. This was done in the interest of safety in making test readings within the limited space available for the experiment. However, all loading applied to the test units was based on 24-inch spacing and all data interpretation was made on this basis.

Long-Term Load Tests

Each truss pair and the joist pair was flexed by loading them to design dead load plus design live load, then removing the loads, twice prior to beginning the long-term test. The dead load included the measured dead weight of the test units. The remainder of dead load and live load was applied by using solid concrete blocks trimmed with bricks and lead weights, placed so as to distribute the load as evenly as possible but also to prevent bridging of the load units. During the preliminary loading, the design load (DL + LL) was carried by the truss and joist pairs for a period of 30 minutes before removing the load. Design live and dead loads are given in Figure 3.

After pre-loading, the long-term testing began by loading the test units with dead load (DL) plus 1/2 live load (LL). The use of the design dead load plus 1/2 design live load was considered by the authors and FHA engineers to be both adequate and realistic for long-term testing.

Again, the dead load included the measured dead weight of the test units and the remainder of the DL plus 1/2 LL was applied with solid concrete blocks trimmed to precise values with bricks and lead weights. The deflection measurement apparatus was installed prior to this final loading, and all initial deflection measurements reported are relative to the initial deflection at dead load. These loads were also placed so as to avoid bridging of the loading elements.

Selected plated joints on the truss units were spray painted to enable detection of possible visible signs of slip during the long-term testing if it should occur.

Standard thermometers, both inside and outside the testing building, and a continuous reading hygrothermograph, recording temperature and relative humidity, were used to monitor surrounding conditions. These records were maintained for the first several years but were later discontinued since no correlation with creep could be determined.

Deflection readings were recorded to develop a deflection history for each test unit over the ten-year period, and are shown plotted in Figures 4 through 8. The plots represent average readings for each pair of test elements. Readings were less frequent in the last five years since the annual patterns of creep were well-established by then. The deflection readings were closely spaced in time for the first days and then were taken at longer intervals according to the observed rate of deflection change. Numerical values of average deflections of test element pairs at selected times are given in Table 1.

Figures 4 through 8 also show annual cycles of deflection superimposed on a long- term trend, which is generally curvilinear for approximately three years and then generally linear for the remainder of the test. The long-term trend resembles a common wood creep curve. The tests began in mid-September in 1977, so the year marking on these figures indicate mid-September across the chart. The annual cycles are interesting in that they show a period of rapid deflection increase that begins in late spring, followed by a recovery period that ends a year later, but the recovery is not complete. The annual pattern is not visible in the last few years of data because readings were not frequent enough to show it

The annual and long-term trends for the four truss sets appear almost identical in form. The joist pair exhibited the same annual patterns and the same long-term trend except that the upward slope of the later, generally linear, portion is more gentle. The average of the two deflections in the type 1 setup crept past the frequently used deflection limit of L/360 in the first year.

Table 2. Test Results

Statistics are given for trusses tested without prior loading except for initial flexing in the test rack (1977) and for trusses from the same lots that had been loaded for ten years at full dead load plus one-half live load (1987).

	1977 Tests					1987 Tests				
Truss Type	Truss No.	Live Load Defl. In.	Ultimate Load Lbs.	K	Failure Type	Truss No.	Live Load Defl. In.	Ultimate Load Lbs.	K	Failure Type
1	6	0.67	5178	2.70	P	4	0.80	5270	2.75	P
	5	0.86	5292	2.76	P	1	0.66	5692	3.00	P
	2	0.70	5392	2.82	P					
2	1	0.31	4301	2.57	P	5	0.43	3500	2.00	P
	2	0.29	4462	2.69	P	3	0.49	3150	1.75	P
	4	0.33	4350	2.61	P					
3	6	0.51	5383	2.84	P	5	0.72	6880	3.74	S
	2	0.63	5881	3.14	PW	3	0.63	4795	2.49	PW
	4	0.70	5860	3.13	W					
4	6	0.74	6960	3.46	B	1	0.75	6123	3.00	W
	4	0.71	7053	3.52	B	3	0.65	7485	3.76	B
	5	0.64	7239	3.62	B					

K = Ultimate Load Factor where Ultimate Load = Dead Load + K (Live Load)
Failure Codes: P = Plate Peel; W = Wood; PW = Plate Peel with Wood
S = Steel Plate; B = Plate Buckling and Tear

All other setups, including the joists, passed the same relative level in the second year.

Approximately two years prior to termination of the tests, a slight onset of plate peeling (emergence from wood) was observed in the type 2 trusses in a splice plate on the bottom side of the lower chord at a point identified as a splice in Figure 3. Although the peeling was evident, no net slip was visible in the spray paint pattern. Both trusses exhibited the same phenomenon.

Table 1 reports initial deflections for each test setup, followed by two year readings taken in August/September and reported as factors. The factors measure deflection in units of the intitial deflection. For example, the truss type 1 deflection at the end of 10 years was 3.1 times its initial value.

Scanning across lines in Table 1 shows that truss types 1, 3 and 4 developed approximately the same creep and recovery. Truss type 2, which developed the previously noted slight plate emergence, shows evidence that the lower chord splice may have been slipping excessively over the entire 2 to 10 year test interval. This is shown in the respective factors which are all much higher than those for the other truss setups. The spray paint marking did not show this but such a crude system may well be insensitive to the small movements involved.

While the joists show better creep performance in Table 1, it should be noted that their span was limited by deflection, and bending stress was only at 73 percent of the allowable value. In contrast, the truss lower chords were stressed to the full allowable stress value, and the upper chords were stressed to 90 percent of allowable. Some of the difference in creep performance between trusses and joists can be explained by this stress level difference. All of the creep performance difference should not be attributed to creep in the connections. The residual deflection performance of the joists does appear to be superior, which is probably due to some non-recoverable slip in the plate connections.

Final Strength Tests

The long-term deflection tests were terminated in August, 1987, and the units were dismantled for standard short-term strength tests for comparison with the re-sults of the original strength tests. These tests were conducted under the same procedure in the same test equipment as was used in the 1977 strength tests of the matched truss sets. The objective was to determine relative performance within truss types and not between truss type designs. The results of and comparison with the 1977 tests are shown in Table 2.

The joists were not tested to failure in either the 1977 or the 1987 series.

In general, the strength performance observed in Table 2 shows little difference in load capacity and failure type between the 1977 and the 1987 tests. The pair of type 2 trusses tested in 1987 performed below the 1977 level, which was probably due to the early-stage plate peeling noted above. Truss 1 in type 4 failed at a large knot in the lower chord, but at a substantial load. Otherwise plate buckling would have been expected.

Conclusions

The loading used, which was full dead load plus half live load, is much higher than commonplace for residential floors and considered more realistic for long-term performance tests. This level proved itself to be sufficient to cause creep beyond the common L/360 limit within two years. In the 30 years of experience of each author, neither can recall an actual residential floor that showed such a creep deflection in any length of time. This adds support to the notion that the experimental loads were very high in comparison with reality.

All test units carried their loads for the ten-year period without signs of distress except for the onset of plate peel in truss type 2. The spray- painted plate connections gave no visible sign of movement within the joint, but the deflection factor record in Table 1 suggests distress at this connection as early as two years into the experiment.

The deflection records of ten years show patterns that have been observed for bending loads on wood components in previous but unpublished long-term load test experiments. The floor joist set, Figure 8, exhibits the creep behavior of lumber. The truss deflection records, Figures 4 through 7, show the same annual cycle type and general trend that resembles a creep curve for wood under constant environmental conditions.

Truss type 1, Figure 4, crept past L/360 in the first year but this is not interpreted as unusual, since this was the most highly stressed design.

The truss type 2 deflection graph, Figure 5, suggests that its right hand portion may be curving up rather than staying linear. Again, this could be a possible effect of distress in the lower chord splice.

The strength tests of the type 1, 3, and 4 trusses that had been loaded for ten years showed no observable strength or stiffness loss when compared with the respective 1977 tests. The exception was the truss pair with the problematical lower chord splices, type 2. These trusses were not as stiff or as strong as their 1977 counterparts.

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